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(54) **MAGNETOSTRICTIVE WAVEGUIDE DETECTION SIGNAL PROCESSING METHOD AND DEVICE**

(57) A magnetostrictive waveguide detection signal processing method and device, the method involving interception of a raw detection signal so as to obtain an analytical signal u(n) and further bandpass filtering to obtain x(n). The excitation signal length is set as L, letting M = [L/4], and R = [M/2]. With an initial i = 0, intercepting data x(i),..., (i+M-1), and building a matrix A wherein R*(M-R+1), then performing singular value decomposition on the matrix so as to obtain a singular matrix B and feature values λ; setting to zero λ values lower than the median to obtain matrix C, performing a reverse singular transformation on the matrix C to obtain matrix D, and reducing from matrix D a post-processed signal y and calculating the energy z thereof. Letting i = i+1, repeating the steps above until completing calculation of the energies of the post-processed signals of the selected analysis zone, then, on the basis of the distortion characteristics of the energy distribution graph, determining whether any defect is present in the signals. The present method effectively enhances the signal-to-noise ratio in magnetostrictive waveguide detection signals, and detection accuracy.

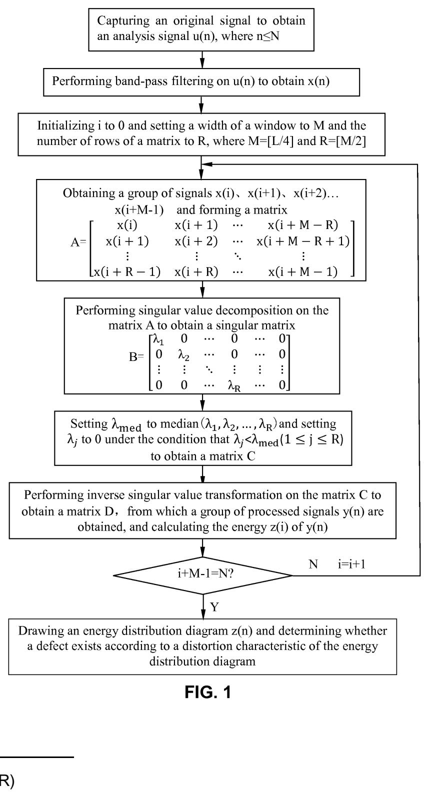

FIG. 1

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Description

[0001] The invention relates to a technical field of non-destructive testing, and more particularly to a method and a device for processing magnetostrictive guided wave detection signals.

[0002] Magnetostrictive guided waves technology has been applied in industry in recent years due to its non-contact and absence of surface polishing. For example, Chinese Patent Publication No. CN101393173A discloses a system for detecting magnetostrictive guided waves in cable-stayed anchorage zone, Chinese Patent Publication No. CN101451976A discloses a method for determining a work point in magnetostrictive guided wave detection, Chinese Patent Publication No. CN101710103A discloses a unidirectional detecting method of magnetostrictive guided waves, and Chinese Patent Publication No. CN102520057A discloses a magnetostrictive guided wave sensor for detecting the interior of a heat exchange tube and a detecting method thereof. However, low conversion efficiency and low signal to noise ratio resulted from non-contact of magnetostrictive guided waves technology restrict the technology's application, which can hardly be avoided by traditional filtering methods. Chinese Patent Publication No. CN101126743A discloses a method for improving signal to noise ratio of magnetostrictive guided waves detection signals, however, the method is extremely inconvenient in field detection for requiring defect-free samples for collecting standard signals.

[0003] It is one objective of the invention to provide a method and a device for processing magnetostrictive guided wave detection signals. The method obtains an energy distribution of a magnetostrictive guided wave detection signal by suppressing the background noise under certain threshold to reduce the impact of external interference on the signal. The method requires no standard samples and greatly facilitates field application.

[0004] The method for processing magnetostrictive guided wave detection signals of the invention is as follows: a method for processing magnetostrictive guided wave detection signals, the method operating to improvedetection accuracy of magnetostrictive guided waves, and comprising steps of:

S1: obtaining an analysis signal u(n) from capturing an original magnetostrictive guided wave detection signal, where $n \leq N$, and N is the length of the analysis signal u(n);

S2: performing band-pass filtering on the analysis signal u(n) to obtain a signal x(n), and initializing i to 0;

S3: obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M, where M = [L/4], and L is the length of the excitation signal;

S4: forming a matrix A of R*(M-R+1), where R = [M/2]:

$$A = \begin{bmatrix} x(i) & x(i+1) & \cdots & x(i+M-R) \\ x(i+1) & x(i+2) & \cdots & x(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(i+R-1) & x(i+R) & \cdots & x(i+M-1) \end{bmatrix};$$

S5: performing singular value decomposition on the matrix A to obtain a singular matrix B:

$$B = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \lambda_R & \cdots & 0 \end{bmatrix},$$

λ_j represents an eigenvalue, and j = 1, 2, ...R;

S6: setting eigenvalues in the matrix B smaller than the median to 0 to obtain a matrix C, and performing inverse singular value transformation on the matrix C to obtain a matrix D:

$$D = \begin{bmatrix} y(i) & y(i+1) & \cdots & y(i+M-R) \\ y(i+1) & y(i+2) & \cdots & y(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ y(i+R-1) & y(i+R) & \cdots & y(i+M-1) \end{bmatrix};$$

S7: recovering a group of processed signals y(i), y(i+1), ..., y(i+M-1) from the matrix D and calculating energy z of the group of processed signals; and

S8: setting i to (i+1) and repeating steps S3-S7 until i = N+1-M to finish calculating the energy of processed signals of the selected analysis area.

[0005] The method further comprises steps of:

S9: drawing an energy distribution diagram z(n) according to the energy of processed signals of the selected analysis area obtained by the step S8; and

S10: determining whether a defect exists in a sample according to a distortion characteristic of the energy distribution diagram z(n).

[0006] The device for processing magnetostrictive guided wave detection signals of the invention is as follows: a device for processing magnetostrictive guided wave detection signals, the device operating to improve detection accuracy of magnetostrictive guided waves, and comprising:

a signal capturing unit, operable for capturing an original magnetostrictive guided wave detection signal to obtain an analysis signal u(n), where $n \leq N$, and N is the length of the analysis signal u(n);

a band-pass filter, connected to the signal capturing unit and operable for performing band-pass filtering on the analysis signal u(n) to obtain a signal x(n); and

a signal processing unit, connected to the band-pass filter and operable for denoising the signal x(n) and calculating the energy distribution of the denoised signal; where

the signal processing unit operates as follows:

obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M, where M = [L/4], and L is the length of the excitation signal; and initializing i to 0;
forming a matrix A of R*(M-R+1), where R = [M/2]:

$$A = \begin{bmatrix} x(i) & x(i+1) & \cdots & x(i+M-R) \\ x(i+1) & x(i+2) & \cdots & x(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(i+R-1) & x(i+R) & \cdots & x(i+M-1) \end{bmatrix};$$

performing singular value decomposition on the matrix A to obtain a singular matrix B:

$$B = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \lambda_R & \cdots & 0 \end{bmatrix},$$

λ_j represents an eigenvalue, and j = 1, 2, ... R;
setting eigenvalues in the matrix B smaller than the median to 0 to obtain a matrix C, and performing inverse singular value transformation on the matrix C to obtain a matrix D:

$$D = \begin{bmatrix} y(i) & y(i+1) & \cdots & y(i+M-R) \\ y(i+1) & y(i+2) & \cdots & y(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ y(i+R-1) & y(i+R) & \cdots & y(i+M-1) \end{bmatrix};$$

recovering a group of processed signals y(i), y(i+1), ..., y(i+M-1) from the matrix D and calculating energy z of the group of processed signals; and setting i to (i+1) and repeating the steps of obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M and processing the signals until i = N+1-M to finish calculating the energy of processed signals of the selected analysis area.

[0007] The device further comprises a defect detecting unit, connected to the signal processing unit, and operable for drawing an energy distribution diagram z(n) according to the energy of processed signals of the selected analysis area and determining whether a defect exists in a test sample according to a distortion characteristic of the energy distribution diagram z(n).

[0008] The principle of the present invention is that a magnetostrctiveguided wave propagating in a sample at a group velocity is reflected, diffracted or transmitted in a different way due to existence of defects and other irregular structures which causes changes in the signal waveform and the propagating energy in corresponding positions. In prior art, a defect-freesample is required for collecting a standard signal, and differential and other processes should be carried out on a test signal and the standard signal, which is unfavorable for field detection. However, the present invention obtains an energy distribution of a magnetostrictive guided wave detection signal by suppressing the background noise under certain threshold to reduce the impact of external interference on the signal, so that the accuracy of magnetostrictive guided wave signal detection is improved by improving the signal to noise ratio. The method requires no standard samples and greatly facilitates field application.

[0009] Further description of the invention will be given below in conjunction with accompanying drawings and specific embodiments.

FIG. 1 is a flow chart of a method for processing magnetostrictive guided wave detection signals according to the present invention;

FIG. 2 is a schematic diagram of a device for processing magnetostrictive guided wave detection signals according to the present invention;

FIG. 3 is an experimental layout for detecting a defective standard pipe according to one embodiment of the present invention;

FIG. 4 is a schematic diagram of an original signal detected from a defective pipe with an outside diameter of 25 mm and an inside diameter of 20 mm according to one embodiment of the present invention;

FIG. 5 is a schematic diagram of an analysis signal obtained by capturing an original signal detected from a defective pipe;

FIG. 6 is an energy distribution diagram of signals obtained by processing an analysis signal of a defective pipe by the method of the present invention;

FIG. 7 is an experimental layout for detecting a defect-freestandard pipe according to one embodiment of the present invention;

FIG. 8 is a schematic diagram of an original signal detected from a defect-freepipe with an outside diameter of 25 mm and an inside diameter of 20 mm;

FIG. 9 is a schematic diagram of an analysis signal obtained by capturing an original signal detected from a defect-freepipe; and

FIG. 10 is an energy distribution diagram of signals obtained by processing an analysis signal of a defect-freepipe by the method of the present invention.

[0010] For further illustrating the invention, experiments detailing a method and a device for processing magnetostrictive guided wave detection signals are described below. It should be noted that the following examples are intended to describe and not to limit the invention.

[0011] FIG. 1 is a flow chart of a method for improving accuracy of magnetostrictive guided wave detection according to the present invention. As shown in FIG. 1, the method for improving accuracy of magnetostrictive guided wave detection comprises steps of:

S1: obtaining an analysis signal u(n)capturing an original magnetostrictive guided wave detection signal, where $n \le N$, and N is the length of the analysis signal u(n);
S2: performing band-pass filtering on the analysis signal u(n) to obtain a signal x(n), and initializing i to 0;
S3: obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M, where M = [L/4], and L is the length of the excitation signal;
S4: forming a matrix A of R*(M-R+1), where R = [M/2]:

$$A = \begin{bmatrix} x(i) & x(i+1) & \cdots & x(i+M-R) \\ x(i+1) & x(i+2) & \cdots & x(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(i+R-1) & x(i+R) & \cdots & x(i+M-1) \end{bmatrix};$$

S5: performing singular value decomposition on the matrix A to obtain a singular matrix B:

$$B = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \lambda_R & \cdots & 0 \end{bmatrix},$$

λ_j represents an eigenvalue, and j = 1, 2, ... R;

S6: setting λ_{med} to median ($\lambda_1, \lambda_2, ..., \lambda_r$) and setting λ_j to 0 under the condition that $\lambda_j < \lambda_{med}$ ($1 \le j \le R$) to obtain a matrix C, namely setting eigenvalues in the matrix B smaller than the median to 0 to obtain the matrix C; and performing inverse singular value transformation on the matrix C to obtain a matrix D:

$$D = \begin{bmatrix} y(i) & y(i+1) & \cdots & y(i+M-R) \\ y(i+1) & y(i+2) & \cdots & y(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ y(i+R-1) & y(i+R) & \cdots & y(i+M-1) \end{bmatrix};$$

S7: recovering a group of processed signals y(i), y(i+1), ..., y(i+M-1) from the matrix D and calculating energy z of the group of processed signals;

S8: setting i to (i+1) and repeating steps S3-S7 until i = N+1-M to finish calculating the energy of processed signals of the selected analysis area;

S9: drawing an energy distribution diagram z(n) according to the energy of processed signals of the selected analysis area obtained by the step S8; and

S10: determining whether a defect exists in a sample according to a distortion characteristic of the energy distribution diagram z(n).

[0012] FIG. 2 is a schematic diagram of a device for processing magnetostrictive guided wave detection signals according to the present invention. As shown in FIG. 2, the device for processing magnetostrictive guided wave detection signals comprises a signal capturing unit 1, a band-pass filter 2 connected to the signal capturing unit 1, a signal processing unit 3 connected to the band-pass filter 2, and a defect detecting unit 4 connected to the signal processing unit 3. The signal capturing unit 1 is operable for capturing an original magnetostrictive guided wave detection signal to obtain an analysis signal u(n), where $n \le N$, and N is the length of the analysis signal u(n). The band-pass filter 2 is operable for performing band-pass filtering on the analysis signal u(n) to obtain a signal x(n). The signal processing unit 3 is operable for denoising the signal x(n) and calculating the energy distribution of the denoised signal, where the signal processing unit 3 operates as follows:

obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M, where M = [L/4], and L is the length of the excitation signal; and initializing i to 0;

forming a matrix A of R*(M-R+1), where R = [M/2]:

$$A = \begin{bmatrix} x(i) & x(i+1) & \cdots & x(i+M-R) \\ x(i+1) & x(i+2) & \cdots & x(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(i+R-1) & x(i+R) & \cdots & x(i+M-1) \end{bmatrix};$$

performing singular value decomposition on the matrix A to obtain a singular matrix B:

$$B = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \lambda_R & \cdots & 0 \end{bmatrix},$$

λ_j represents an eigenvalue, and j = 1, 2, ... R;
setting eigenvalues in the matrix B smaller than the median to 0 to obtain a matrix C, and performing inverse singular value transformation on the matrix C to obtain a matrix D:

$$D = \begin{bmatrix} y(i) & y(i+1) & \cdots & y(i+M-R) \\ y(i+1) & y(i+2) & \cdots & y(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ y(i+R-1) & y(i+R) & \cdots & y(i+M-1) \end{bmatrix};$$

recovering a group of processed signals y(i), y(i+1), ..., y(i+M-1) from the matrix D and calculating energy z of the group of processed signals; and setting i to (i+1) and repeating the steps of obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M and processing the signals until i = N+1-M to finish calculating the energy of processed signals of the selected analysis area.

[0013] The defect detecting unit 4 is operable for drawing an energy distribution diagram z(n) according to the energy of processed signals of the selected analysis area and determining whether a defect exists in a test sample according to a distortion characteristic of the energy distribution diagram z(n).

[0014] A specific embodiment is provided below according to the present invention.

[0015] As shown in FIG. 3, a defective heat exchange pipe with an outside diameter of 25 mm, an inside diameter of 20 mm, and a length of 2800 mm is used as a test sample. An excitation coil is 100 mm away from the left end of the pipe, a receiving coil is 600 mm away from the left endof the pipe, and a hole with a diameter of 5 mm exists 2000 mm away from the left endof the pipe. The excitation frequency is 90 kHz, the sampling frequency is 2000 kHz, and the guided wave speed is about 3200 m/s. A schematic diagram of an original signal detected from the defective heat exchange pipe is shown in FIG. 4, which includes an electromagnetic pulse signal M, a signal S passed through a receiving sensor for the first time, and a signal S1 reflected by the rightend for the first time. In order to facilitate analysis, the original signal in FIG. 4 is cut to obtain an analysis signal of the defective pipe ranging from S to S1, which is shown in FIG. 5. A defective signal should exist when t equals 1.03 ms according to calculation, which cannot be identified according to FIG. 5. The analysis signal of the defective pipe is processed by the method of the present invent by selecting a rectangular window with a width of 6 and forming a matrix of 3*4. FIG. 6 is an energy distribution diagram of signals obtained by processing the analysis signal of the defective pipe by the method of the present invention. As shown in FIG. 6, a significant distortion P occurs in the energy at 1.03 ms and the peak value of P mutates greatly. The occurring time matches with the theoretical time, so that it can be concluded that the distortion is caused by the defection.

[0016] A defect-free heat exchange pipe having the same specifications with the defective heat exchange pipe is provided. The experimental layout, the excitation frequency, the sampling frequency and the guided wave speed stay unchanged. FIG. 7 is the experimental layout for detecting the defect-free pipe. FIG. 8 is a schematic diagram of an original signal detected from the defect-free pipe, which is cut to obtain an analysis signal of the defect-free pipe ranging from S to S1. FIG. 9 is a schematic diagram of the analysis signal obtained by capturing the original signal detected from the defect-free pipe. FIG. 10 is an energy distribution diagram of signals obtained by processing the analysis signal of a defect-free pipe by the method of the present invention, unlike the energy distribution diagram of the defective pipe (FIG. 6), no obvious distortion occurs. Therefore, it can be concluded that the method of the present invention is effective and reliable.

[0017] While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

Claims

1. A method for processing magnetostrictive guided wave detection signals, the method operating to improve detection accuracy of magnetostrictive guided waves, and comprising steps of:

S1: obtaining an analysis signal u(n) from capturing an original magnetostrictive guided wave detection signal, where $n \leq N$, and N is the length of the analysis signal u(n);
S2: performing band-pass filtering on the analysis signal u(n) to obtain a signal x(n), and initializing i to 0;
S3: obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M, where M = [L/4], and L is the length of the excitation signal;
S4: forming a matrix A of R*(M-R+1), where R = [M/2]:

$$A = \begin{bmatrix} x(i) & x(i+1) & \cdots & x(i+M-R) \\ x(i+1) & x(i+2) & \cdots & x(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(i+R-1) & x(i+R) & \cdots & x(i+M-1) \end{bmatrix};$$

S5: performing singular value decomposition on the matrix A to obtain a singular matrix B:

$$B = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \lambda_R & \cdots & 0 \end{bmatrix},$$

λ_j represents an eigenvalue, and j = 1, 2, ... R;
S6: setting eigenvalues in the matrix B smaller than the median to 0 to obtain a matrix C, and performing inverse singular value transformation on the matrix C to obtain a matrix D:

$$D = \begin{bmatrix} y(i) & y(i+1) & \cdots & y(i+M-R) \\ y(i+1) & y(i+2) & \cdots & y(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ y(i+R-1) & y(i+R) & \cdots & y(i+M-1) \end{bmatrix};$$

S7: recovering a group of processed signals y(i), y(i+1), ..., y(i+M-1) from the matrix D and calculating energy z of the group of processed signals; and
S8: setting i to (i+1) and repeating steps S3-S7 until i = N+1-M to finish calculating the energy of processed signals of the selected analysis area.

2. The method of claim 1, further comprising steps of:

S9: drawing an energy distribution diagram z(n) according to the energy of processed signals of the selected analysis area obtained by the step S8; and
S10: determining whether a defect exists in a sample according to a distortion characteristic of the energy distribution diagram z(n).

3. A device for processing magnetostrictive guided wave detection signals, the device operating to improving detection accuracy of magnetostrictive guided waves, and comprising:

a signal capturing unit, operable for capturing an original magnetostrictive guided wave detection signal to obtain an analysis signal u(n), where $n \leq N$, and N is the length of the analysis signal u(n);
a band-pass filter, connected to the signal capturing unit and operable for performing band-pass filtering on the analysis signal u(n) to obtain a signal x(n); and
a signal processing unit, connected to the band-pass filter and operable for denoising the signal x(n) and calculating the energy distribution of the denoised signal; where

the signal processing unit operates as follows:

obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M, where M = [L/4], and L is the length of the excitation signal; and initializing i to 0;
forming a matrix A of R*(M-R+1), where R = [M/2]:

$$A = \begin{bmatrix} x(i) & x(i+1) & \cdots & x(i+M-R) \\ x(i+1) & x(i+2) & \cdots & x(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(i+R-1) & x(i+R) & \cdots & x(i+M-1) \end{bmatrix};$$

performing singular value decomposition on the matrix A to obtain a singular matrix B:

$$B = \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \lambda_R & \cdots & 0 \end{bmatrix},$$

λ_j represents an eigenvalue, and j = 1, 2, ... R;
settingeigenvalues in the matrix B smaller than the median to 0 to obtain a matrix C, and performing inverse singular value transformation on the matrix C to obtain a matrix D:

$$D = \begin{bmatrix} y(i) & y(i+1) & \cdots & y(i+M-R) \\ y(i+1) & y(i+2) & \cdots & y(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ y(i+R-1) & y(i+R) & \cdots & y(i+M-1) \end{bmatrix};$$

recovering a group of processed signals y(i), y(i+1), ..., y(i+M-1) from the matrix D and calculating energy z of the group of processed signals; and
setting i to (i+1) and repeating the steps of obtaining a group of signals x(i), x(i+1), ..., x(i+M-1) using a rectangular window with a width of M and processing the signals until i = N+1-M to finish calculating the energy of processed signals of the selected analysis area.

4. The device of claim 3, further comprising a defect detecting unit connected to the signal processing unit, and operable for drawing an energy distribution diagram z(n) according to the energy of processed signals of the selected analysis area and determining whether a defect exists in a test sample according to a distortion characteristic of the energy distribution diagram z(n).

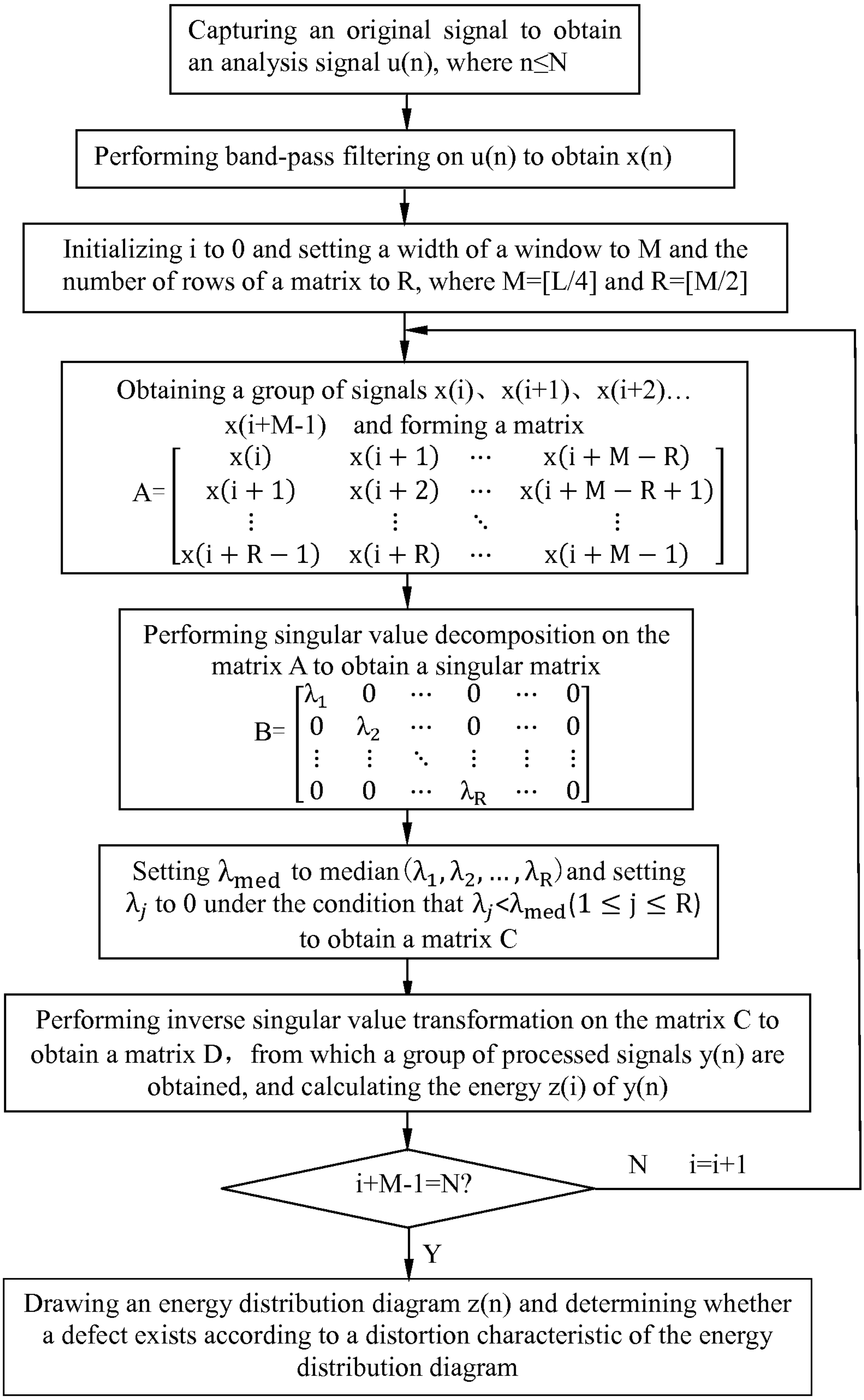
Capturing an original signal to obtain an analysis signal u(n), where n≤N
Performing band-pass filtering on u(n) to obtain x(n)
Initializing i to 0 and setting a width of a window to M and the number of rows of a matrix to R, where M=[L/4] and R=[M/2]
Obtaining a group of signals x(i)、x(i+1)、x(i+2)… x(i+M-1) and forming a matrix
$A=\begin{bmatrix} x(i) & x(i+1) & \cdots & x(i+M-R) \\ x(i+1) & x(i+2) & \cdots & x(i+M-R+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(i+R-1) & x(i+R) & \cdots & x(i+M-1) \end{bmatrix}$
Performing singular value decomposition on the matrix A to obtain a singular matrix
$B=\begin{bmatrix} \lambda_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \lambda_R & \cdots & 0 \end{bmatrix}$
Setting λ_{med} to median$(\lambda_1, \lambda_2, \ldots, \lambda_R)$ and setting λ_j to 0 under the condition that $\lambda_j < \lambda_{med} (1 \le j \le R)$ to obtain a matrix C
Performing inverse singular value transformation on the matrix C to obtain a matrix D，from which a group of processed signals y(n) are obtained, and calculating the energy z(i) of y(n)
i+M-1=N?
N
i=i+1
Y
Drawing an energy distribution diagram z(n) and determining whether a defect exists according to a distortion characteristic of the energy distribution diagram

FIG. 1

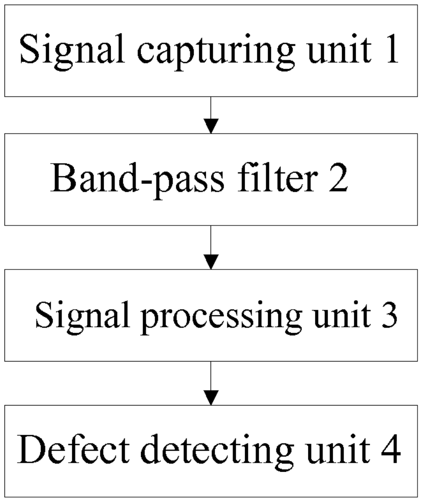

FIG. 2

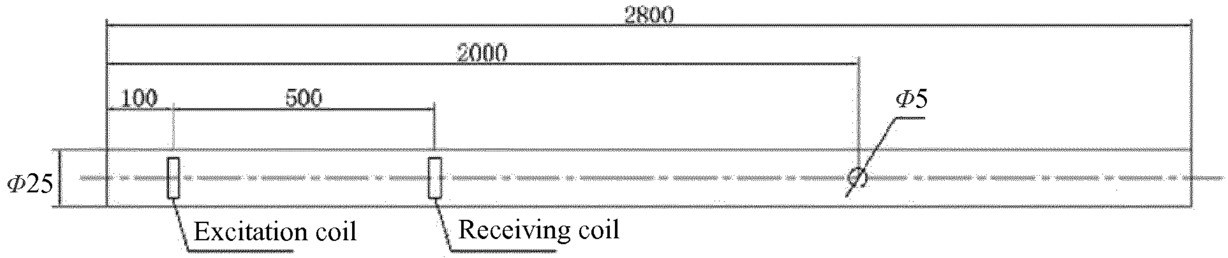

FIG. 3

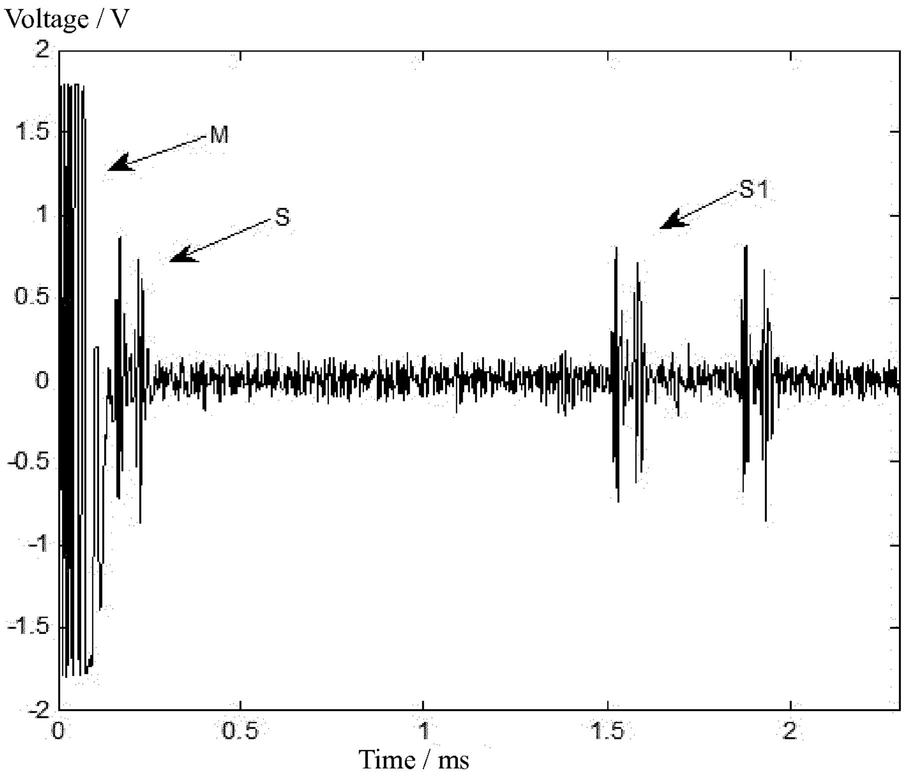

FIG. 4

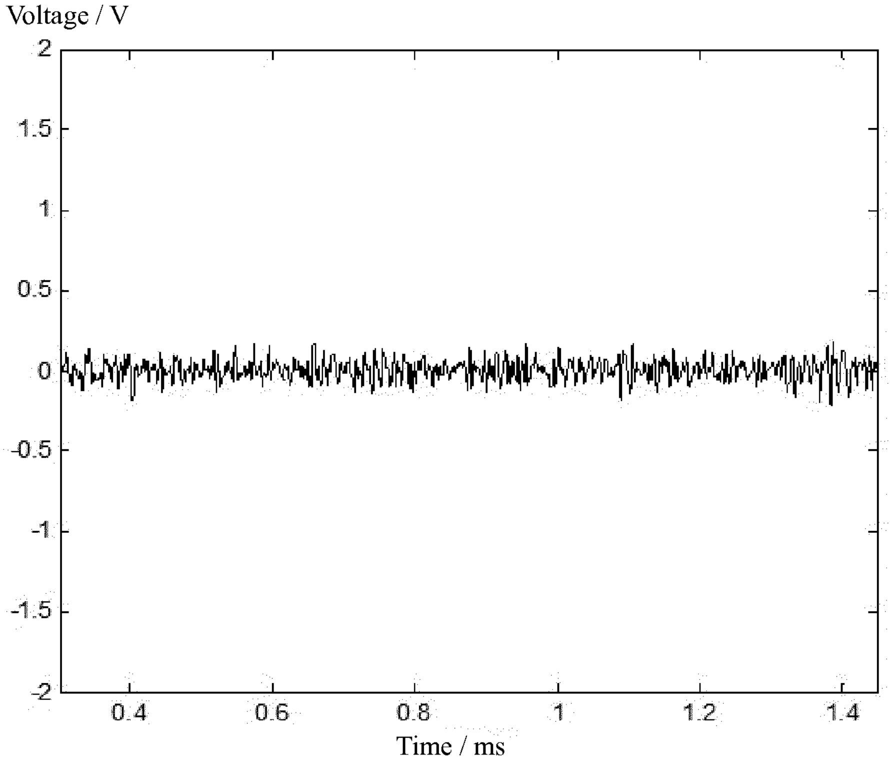
Voltage / V
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0.4
0.6
0.8
1
1.2
1.4
Time / ms

FIG. 5

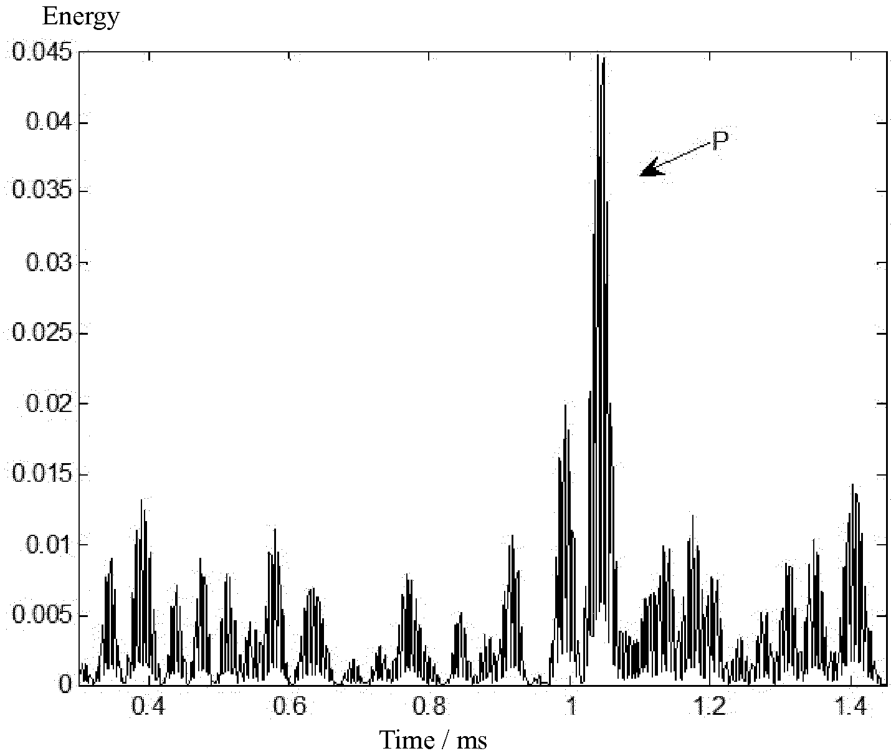
Energy
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
P
0.4
0.6
0.8
1
1.2
1.4
Time / ms

FIG. 6

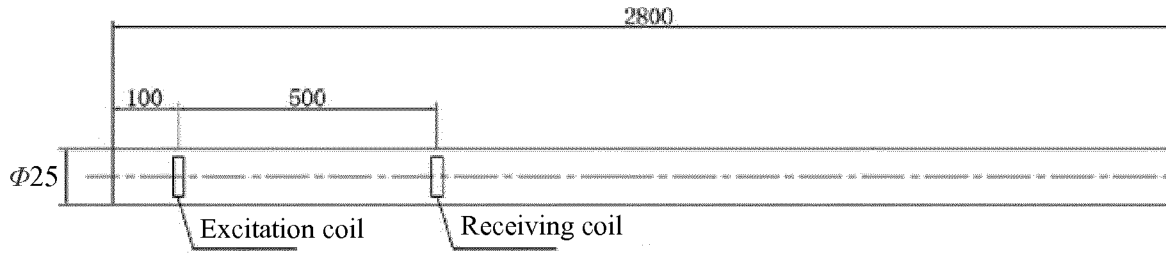
2800
100
500
Φ25
Excitation coil
Receiving coil

FIG. 7

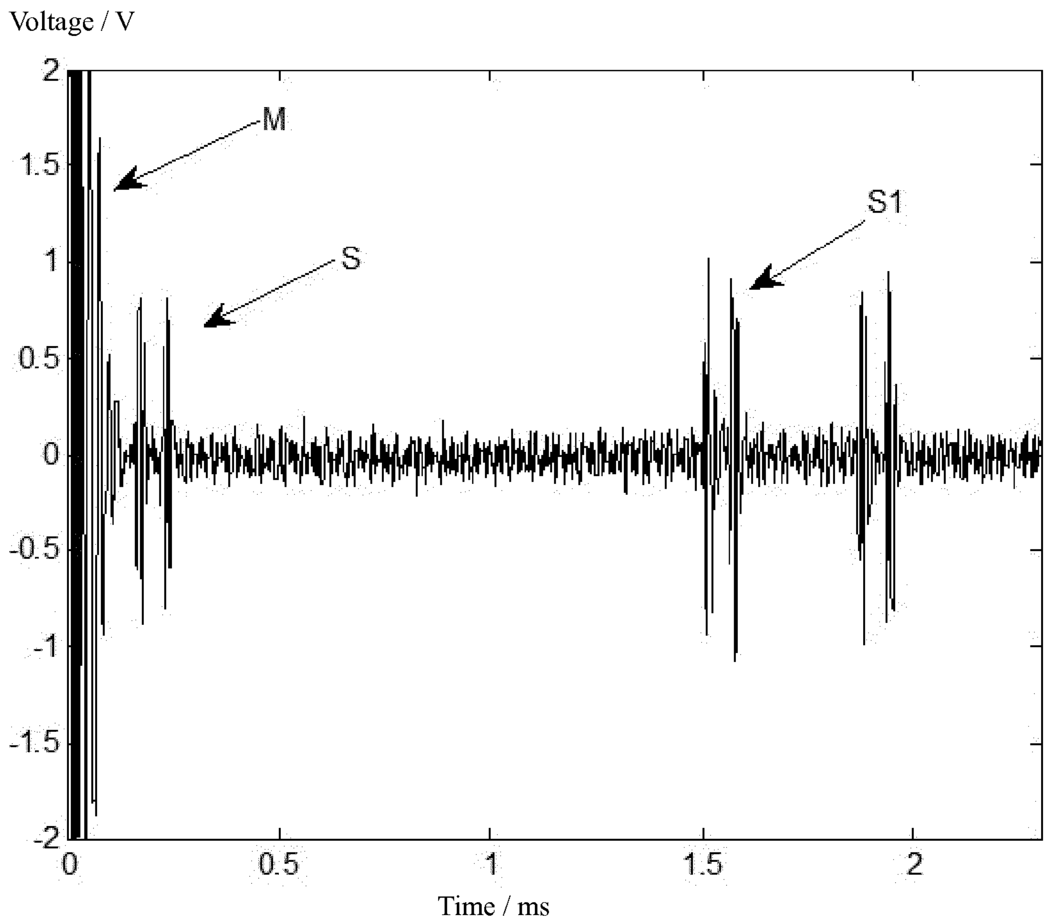
Voltage / V
M
S
S1
Time / ms

FIG. 8

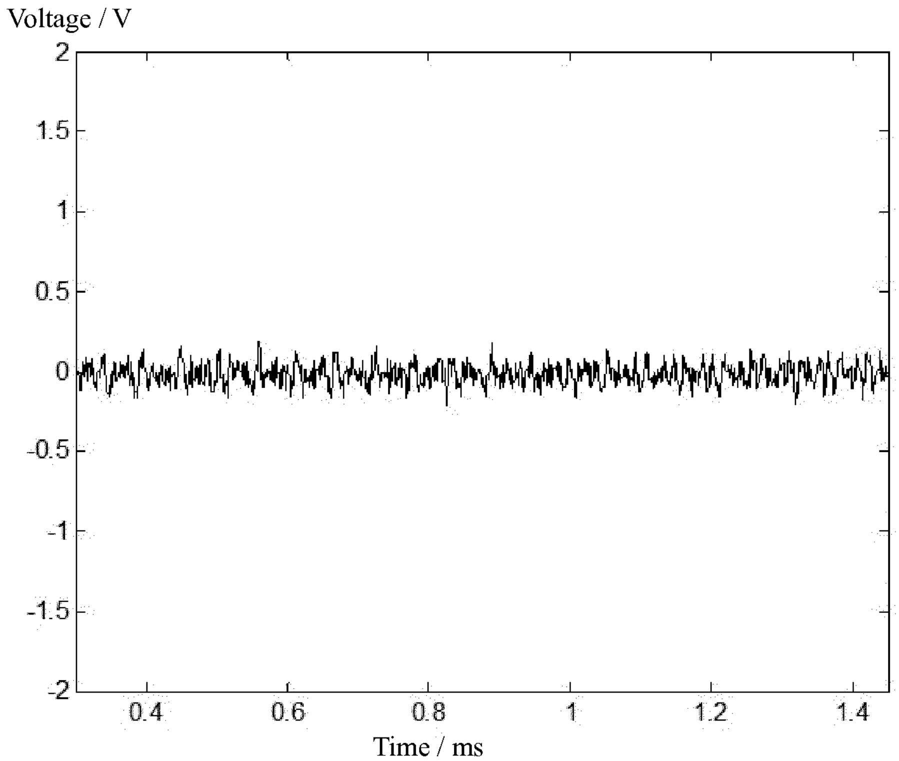
Voltage / V
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0.4
0.6
0.8
1
1.2
1.4
Time / ms

FIG. 9

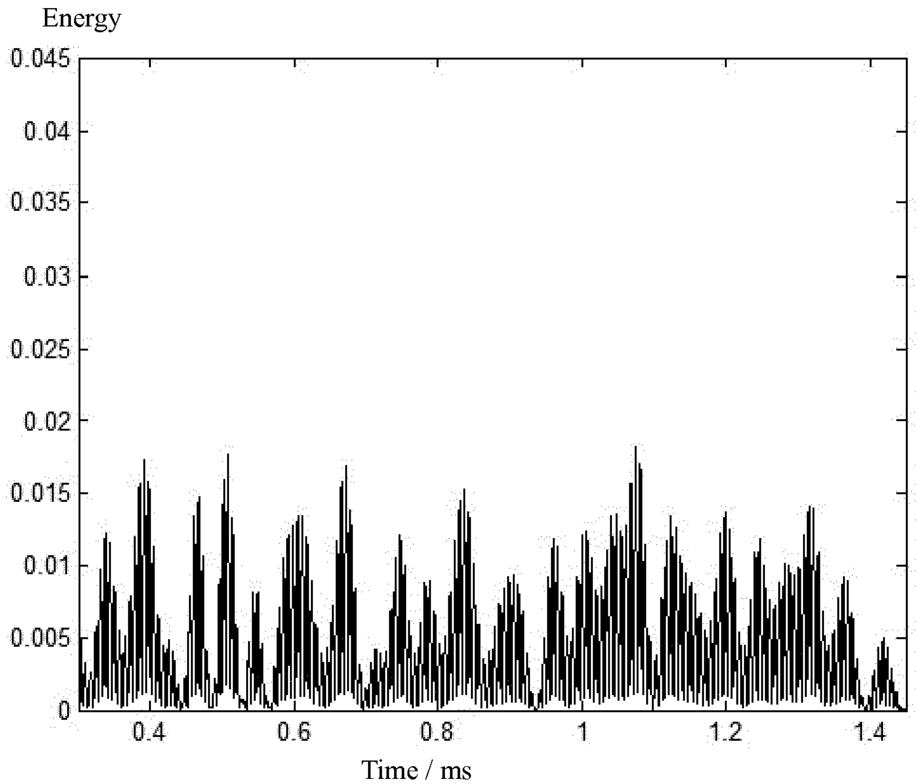
Energy
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.4
0.6
0.8
1
1.2
1.4
Time / ms

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2014/079703

A. CLASSIFICATION OF SUBJECT MATTER

G01N 27/82 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01N -

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNTXT, CNABS, VEN: magnet+ w contract+,magnetostrict+, guid+, energy, threshold, matrix, rectangular, window

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 103424471 A (HARBIN INSTITUTE OF TECHNOLOGY SHENZHEN GRADUATE SCHOOL) 04 December 2013 (04.12.2013) the whole document	1-4
A	CN 101710103 A (HUAZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY) 19 May 2010 (19.05.2010) the whole document	1-4
A	CN 101126743 A (HUAZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY) 20 February 2008 (20.02.2008) the whole document	1-4
A	CN 101451976 A (HUAZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY) 10 June 2009 (10.06.2009) the whole document	1-4
A	US 2012119732 A1 (FBS, INC.) 17 May 2012 (17.05.2012) the whole document	1-4
A	US 6497151 B1 (U. S. PIPE & FOUNDRY COMPANY) 24 December 2002 (24.12.2002) the whole document	1-4

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 July 2014	05 August 2014

Name and mailing address of the ISA	Authorized officer
State Intellectual Property Office of the P. R. China No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088, China Facsimile No. (86-10) 62019451	SHAO, Wen Telephone No. (86-10) 01062413496

Form PCT/ISA /210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2014/079703

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
CN 103424471 A	04 December 2013	None	
CN 101710103 A	19 May 2010	CN 101710103B	20 April 2011
CN 101126743 A	20 February 2008	CN 100559178C	11 November 2009
CN 101451976 A	10 June 2009	CN 101451976B	20 July 2011
US 2012119732 A1	17 May 2012	None	
US 6497151 B1	24 December 2002	None	

Form PCT/ISA /210 (patent family annex) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 101393173 A **[0002]**
- CN 101451976 A **[0002]**
- CN 101710103 A **[0002]**
- CN 102520057 A **[0002]**
- CN 101126743 A **[0002]**